

# Measurement of the Proton Beam Polarization with Ultra Thin Carbon Targets at RHIC

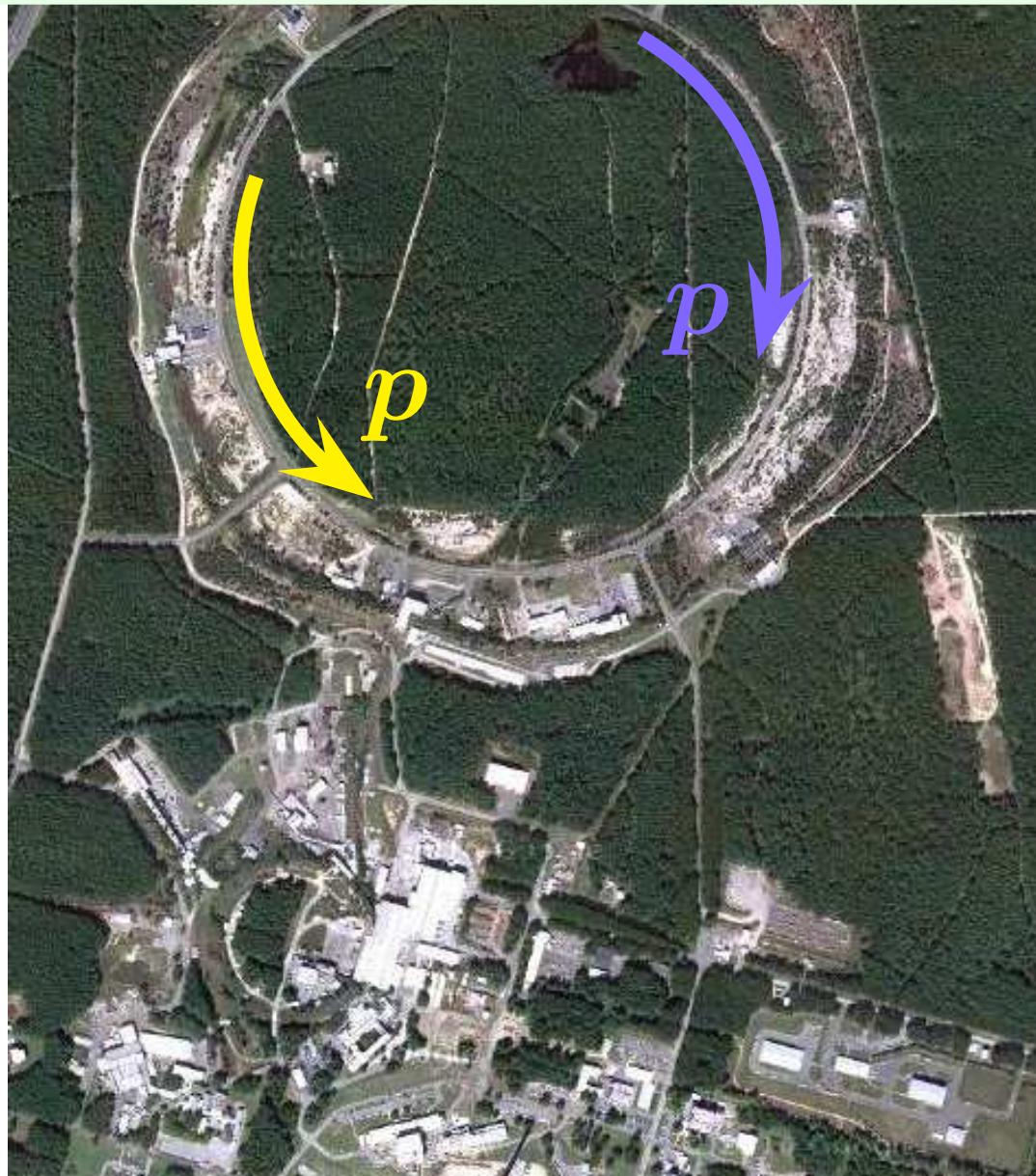
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Brookhaven National Laboratory

for the RHIC Polarimetry Group

Sep 12, 2013

# Relativistic Heavy Ion Collider

world's only polarized proton  
collider

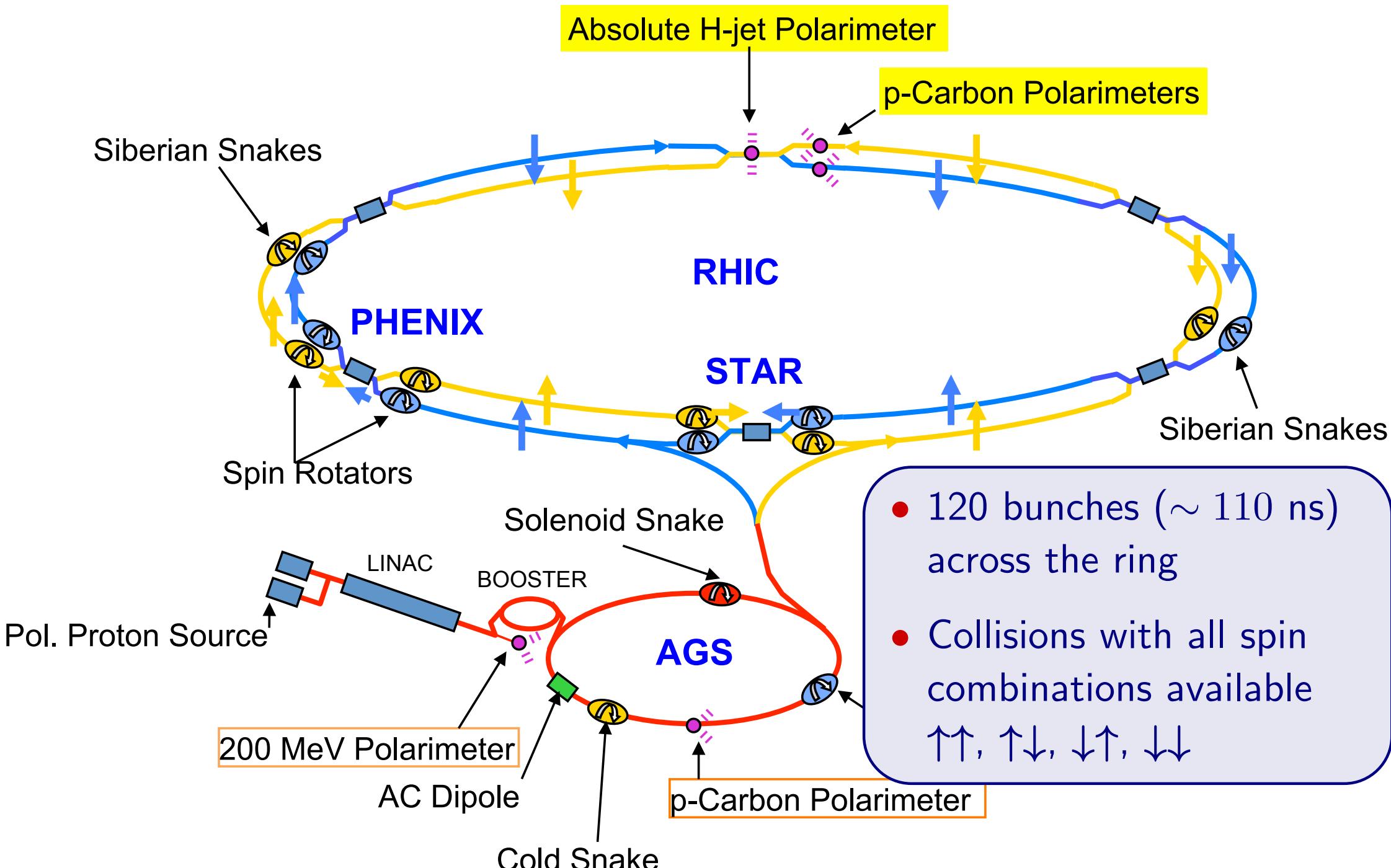


## Outline

- Polarization measurement principles at RHIC
- Overview of RHIC polarimeters
- Polarimeter operations in 2013 run
- Beam polarization profile
- Carbon target challenge
- Systematic Errors and Summary

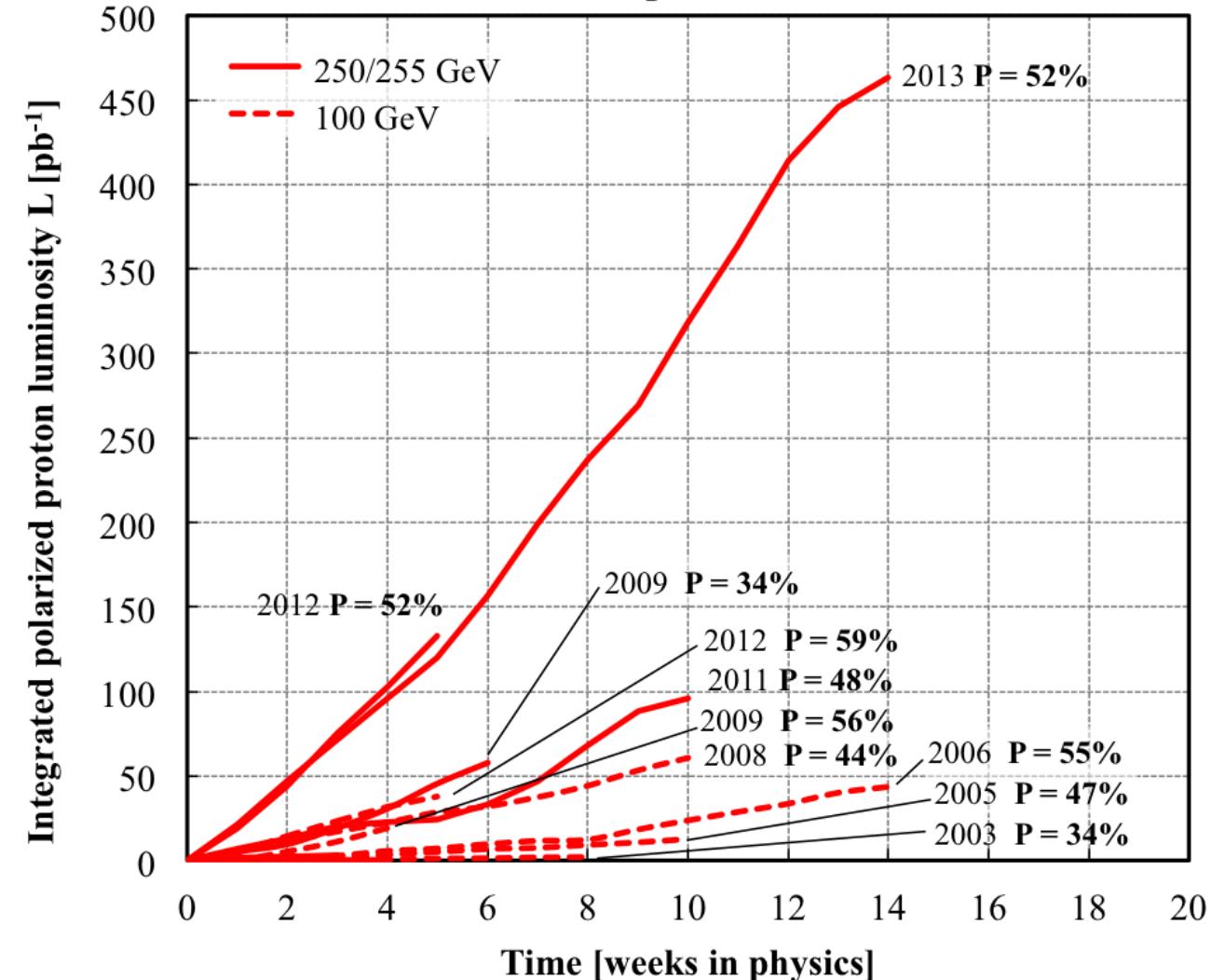
# Accelerator Complex and Polarimeters

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# Recent RHIC Performance

## Polarized proton runs



- 2014: No polarized protons run
- 2015: Expect 100 GeV polarized beams

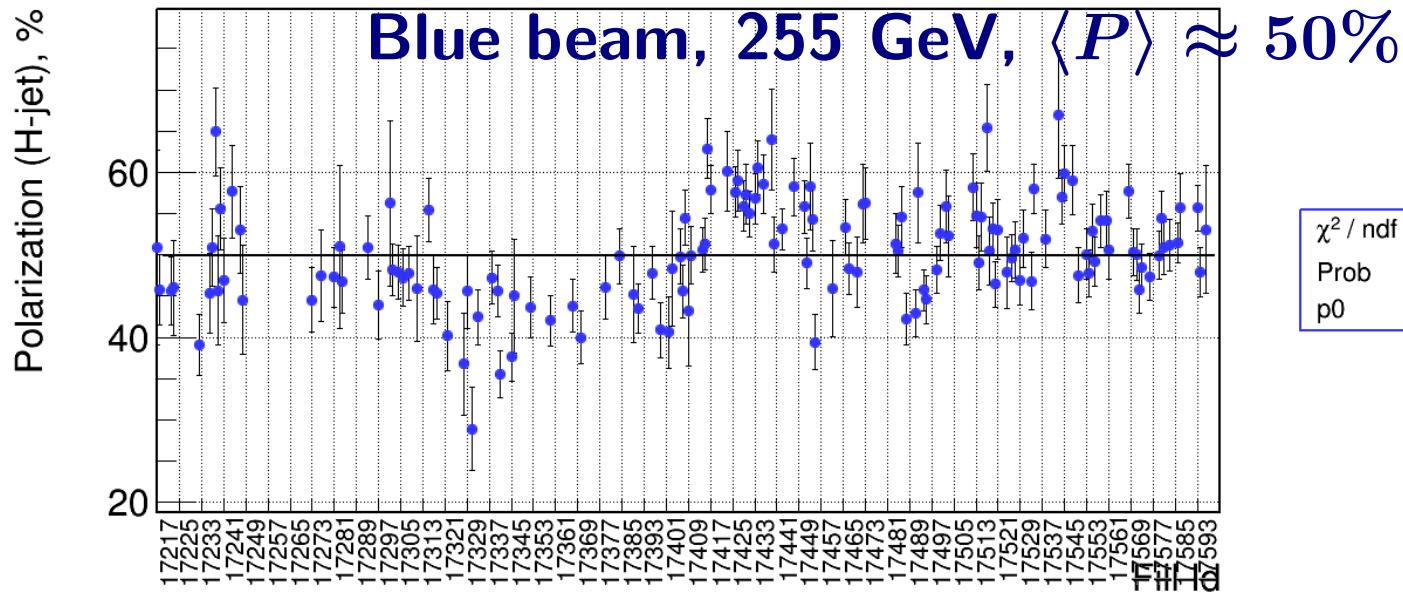
- Excellent RHIC performance

- Each year RHIC sets new record peak, average, or integrated luminosities
- Improves average polarization
- 2009
  - $P = 56\%$  at  $\sqrt{s} = 100 \text{ GeV}$
  - $P = 34\%$  at  $\sqrt{s} = 250 \text{ GeV}$
- 2011
  - $P = 48\%$  at  $\sqrt{s} = 250 \text{ GeV}$
- 2012
  - $P = 59\%$  at  $\sqrt{s} = 100 \text{ GeV}$
  - $P = 52\%$  at  $\sqrt{s} = 255 \text{ GeV}$
- 2013
  - $P = 52\%$  at  $\sqrt{s} = 255 \text{ GeV}$

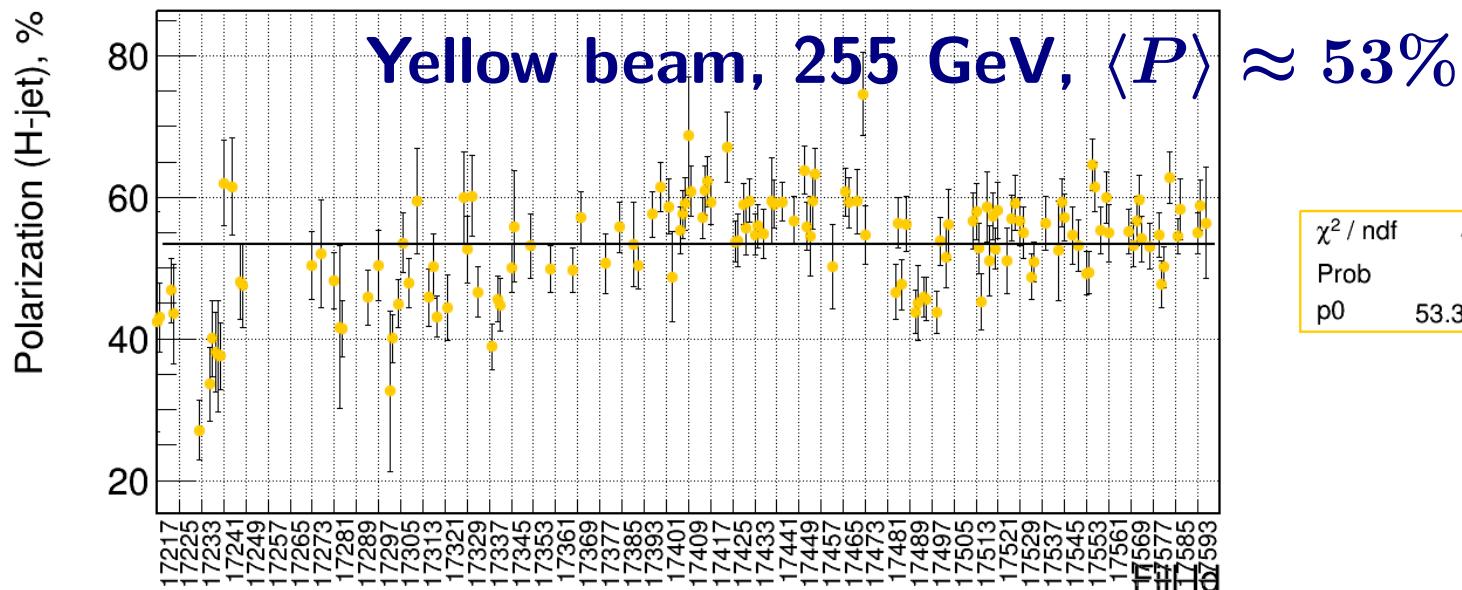
# Average Polarization in 2013 at $E_{\text{beam}} = 255 \text{ GeV}$

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Fills 17217--17601, Analyzed Thu Jun 13 17:40:20 2013, Version 2065:2066, dsmirnov

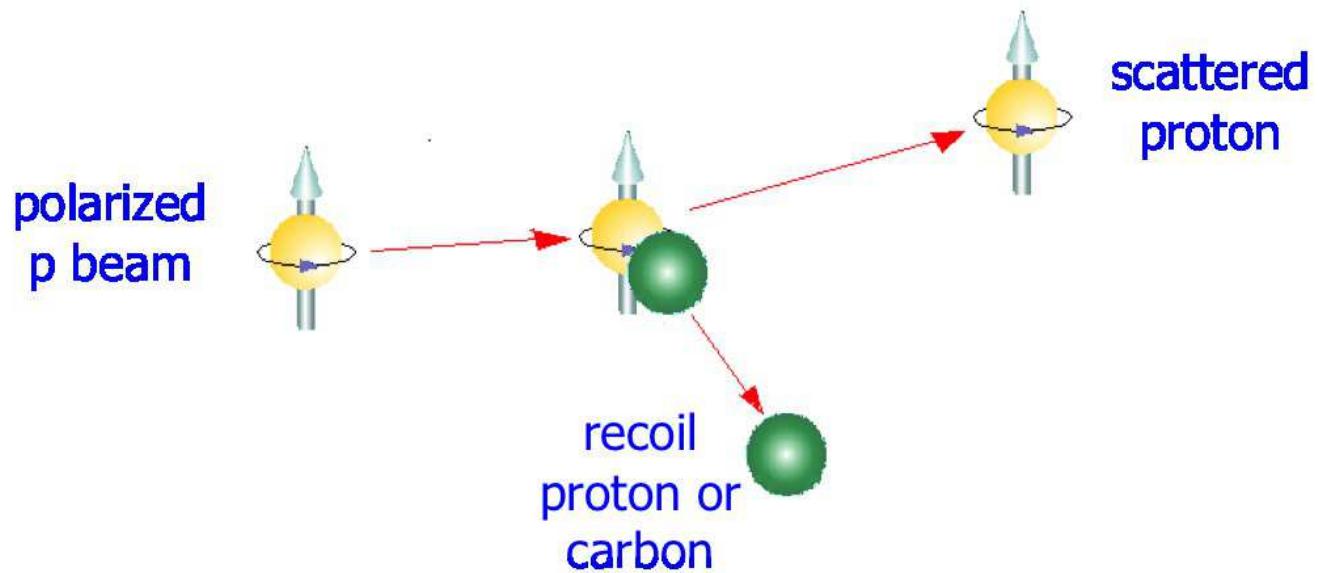


Fills 17217--17601, Analyzed Thu Jun 13 17:40:20 2013, Version 2065:2066, dsmirnov

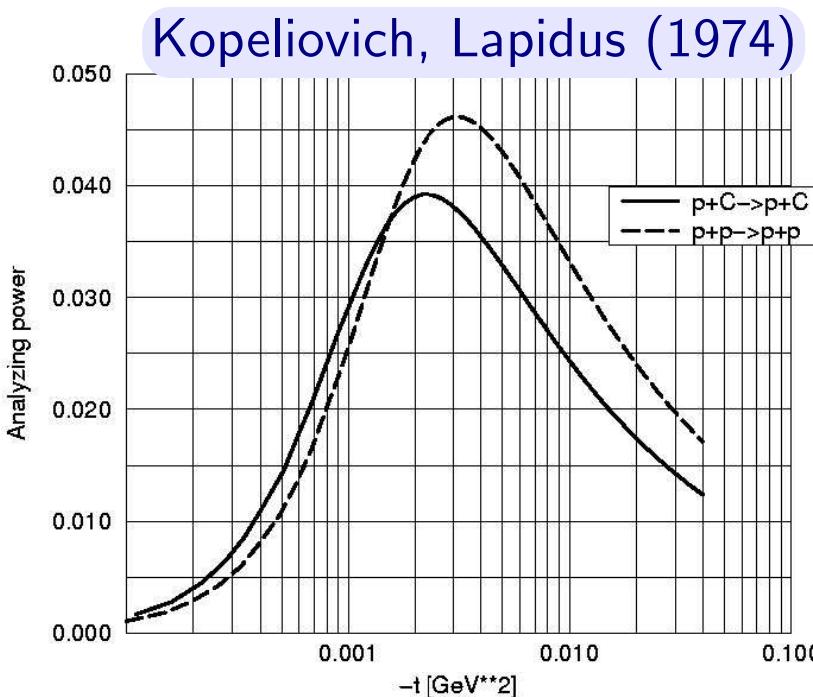


# CNI Polarimetry at RHIC

- In elastic scattering maximum asymmetry  $A_N$  is expected in the region of **Coulomb-Nuclear Interference** where EM and strong amplitudes are comparable in strength



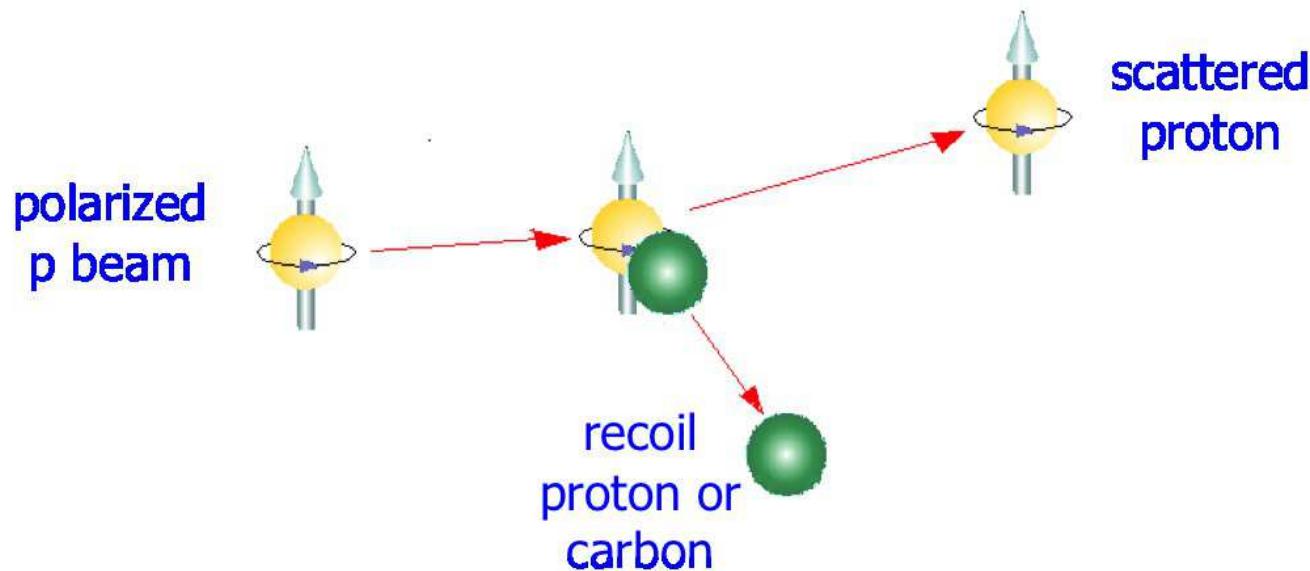
- Measured polarization**  $P = \frac{1}{A_N} \times \epsilon$
- In general, knowledge of  $A_N$  is required



In absence of hadronic spin-flip amplitude analyzing power  $A_N$  can be calculated exactly

# CNI Polarimetry at RHIC

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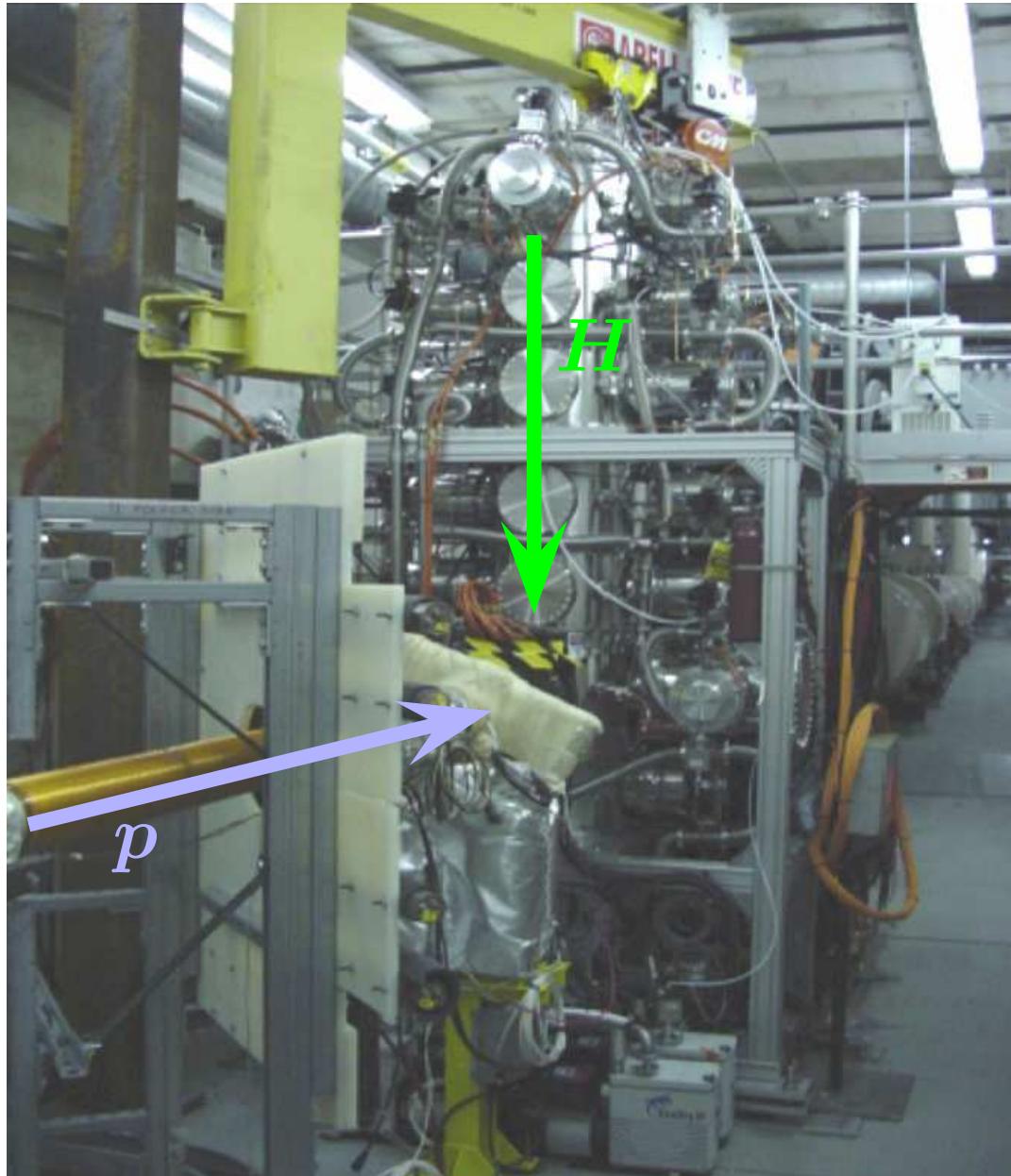


$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}$$

$$\varepsilon = \frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}}$$

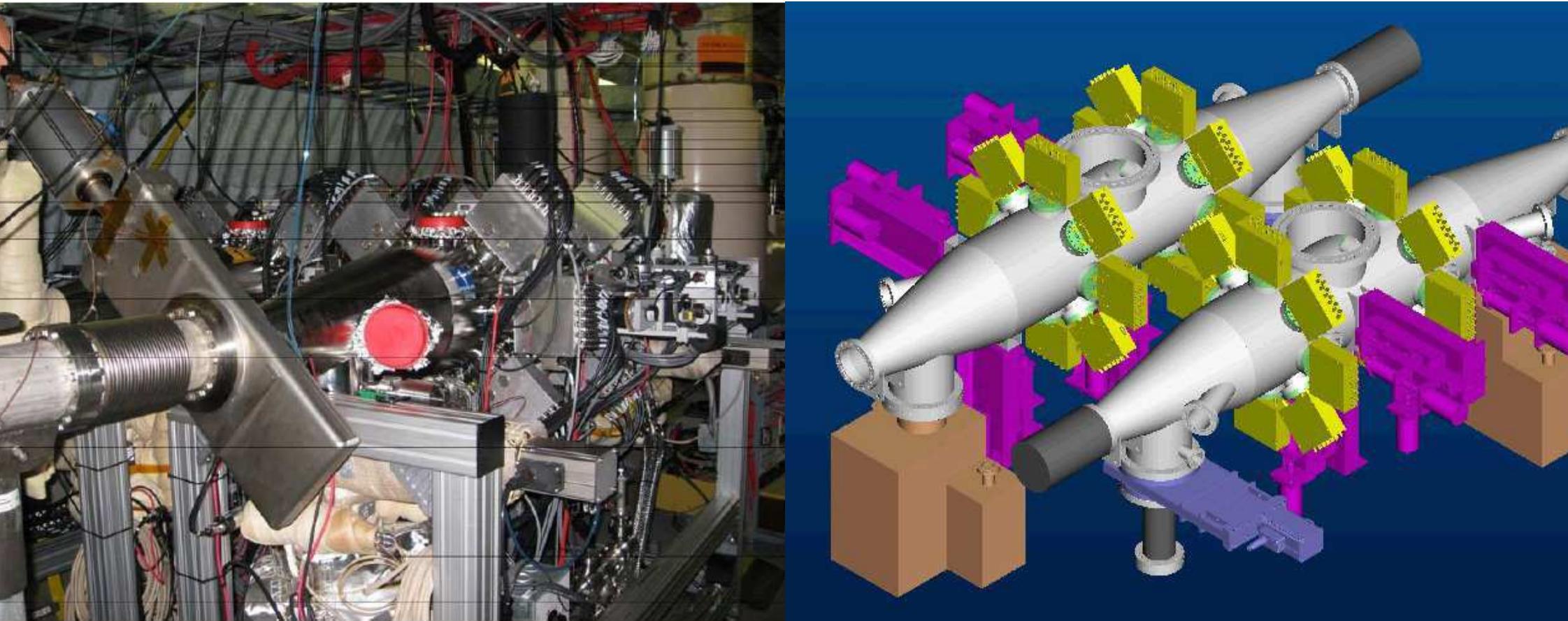
- Measured polarization**  $P = \frac{1}{A_N} \times \varepsilon$
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# RHIC Polarimeters: Hydrogen-Jet (H-Jet) Polarimeter<sup>8 of 23</sup>

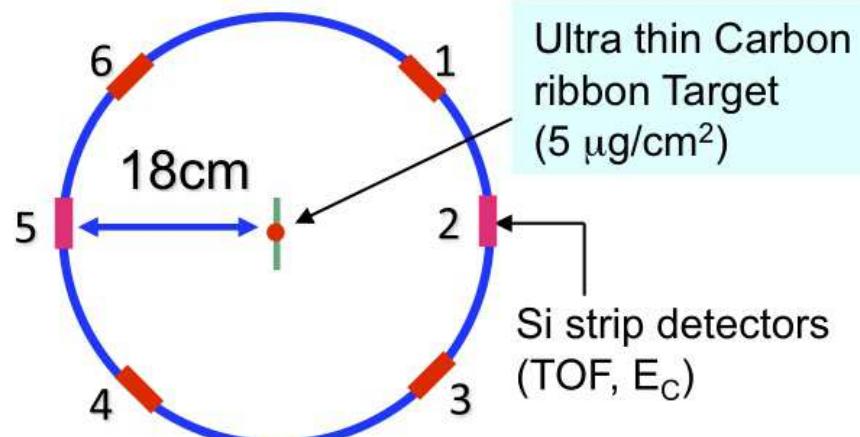


- Provides **average absolute polarization** over a fill ( $\sim 8 - 10$  hours)
- The jet target is polarized  
 $\Rightarrow A_N$  is not required
  - Target polarization cycles through  $\uparrow / 0 / \downarrow$  spin states
- More details in next talk  
**“The polarized hydrogen jet target measurements at RHIC” by Andrei Pobladuev**

# RHIC Polarimeters: p-Carbon Polarimeters

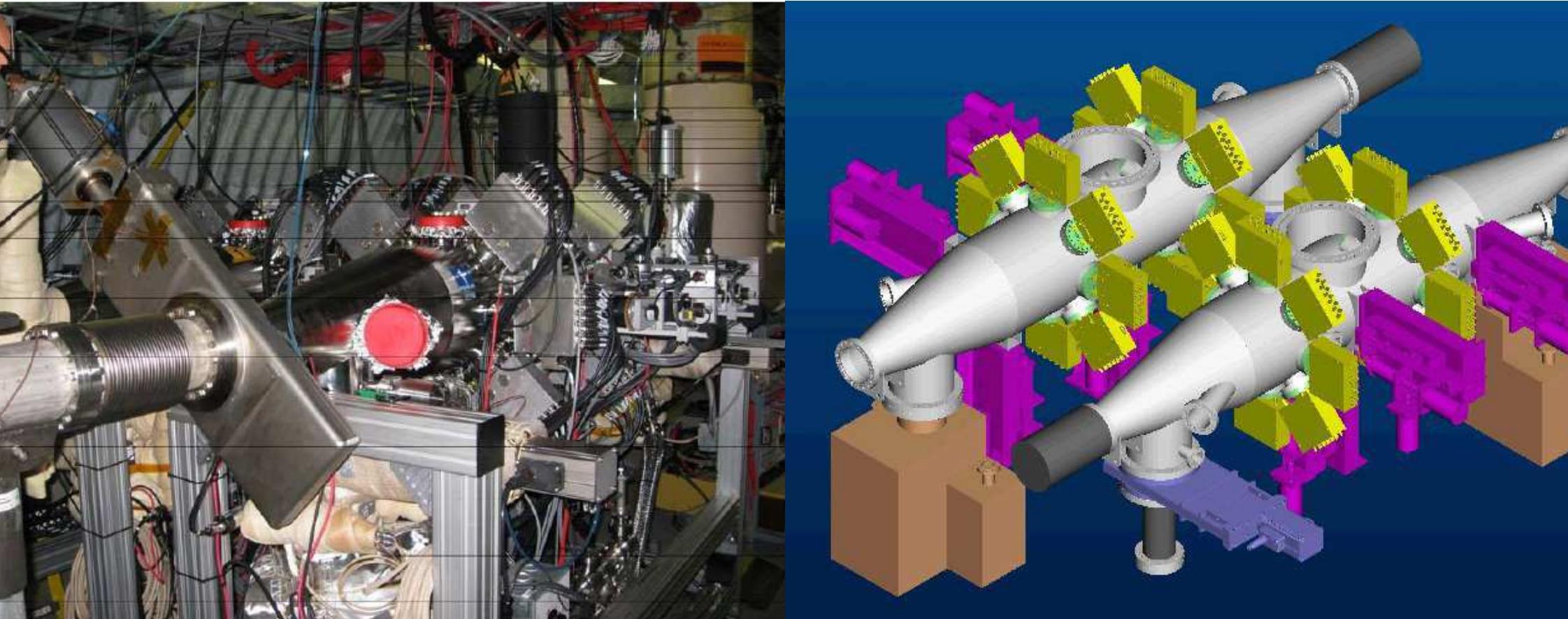


- Two polarimeters in each ring
- $\sim 3 - 4\%$  relative stat. uncert. per measurement
- About four 2-minute measurements per fill
- Bunch-by-bunch polarization

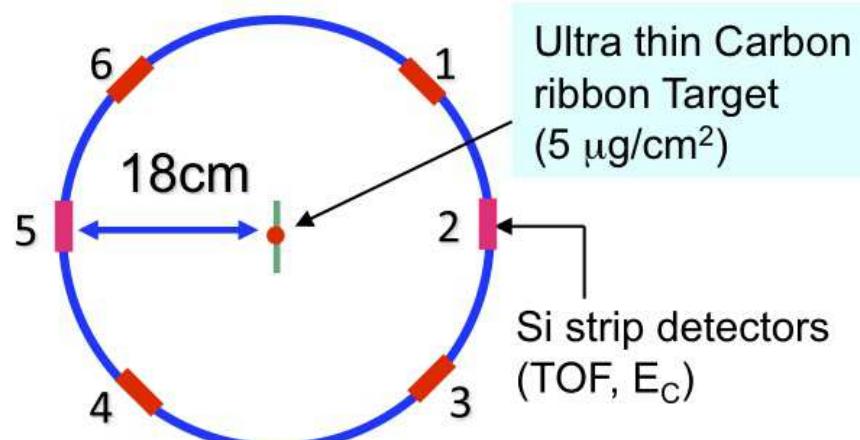


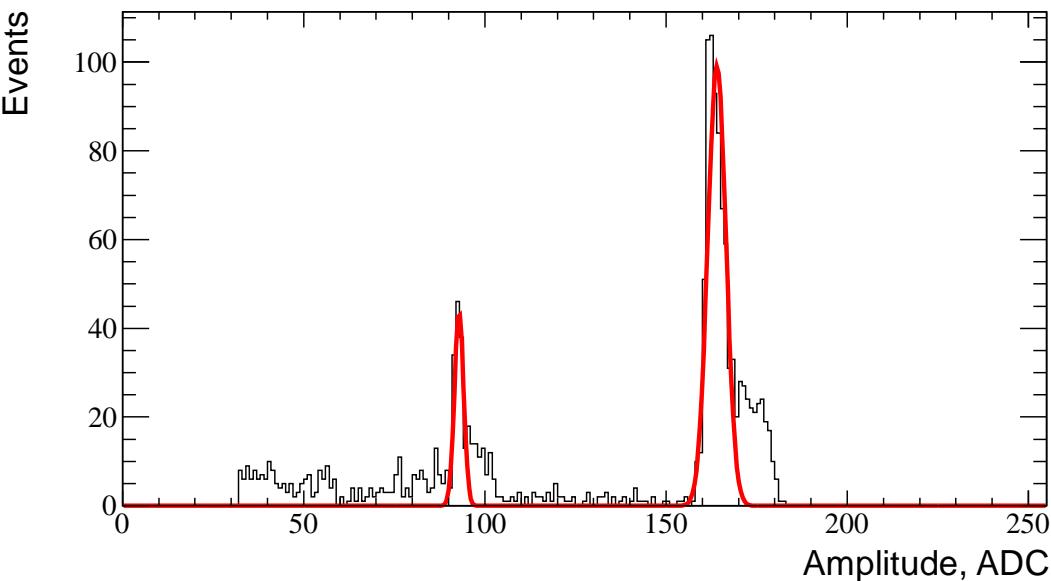
# RHIC Polarimeters: p-Carbon Polarimeters

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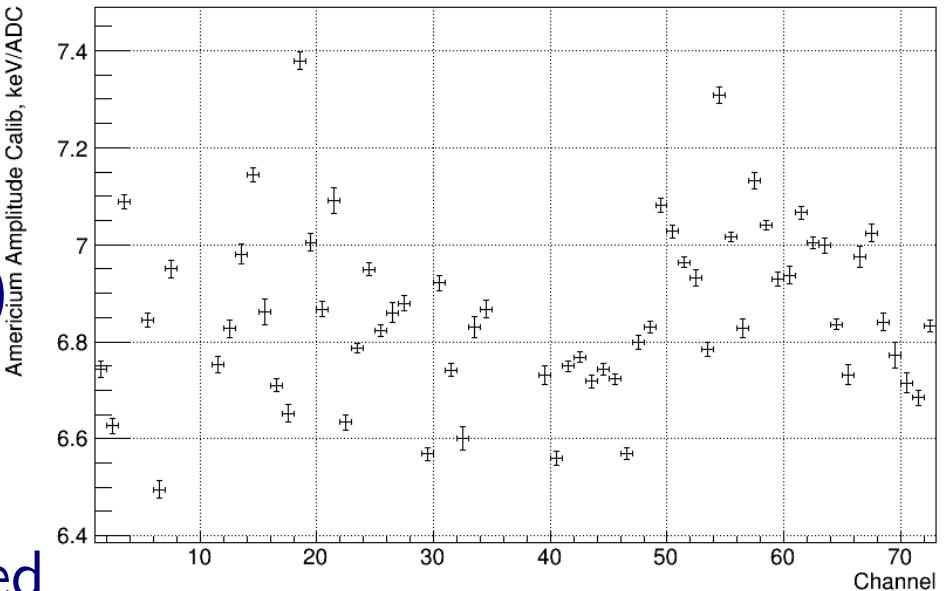
- Vertical and horizontal beam **polarization profiles**
- **Polarization decay** in a fill
- Each polarimeter employs six vertical and six horizontal ultra thin carbon targets





150213a.blu1.alpha0: Recorded Fri Feb 15 14:59:36 2013, Analyzed Sat Aug 24 12:05:45 201

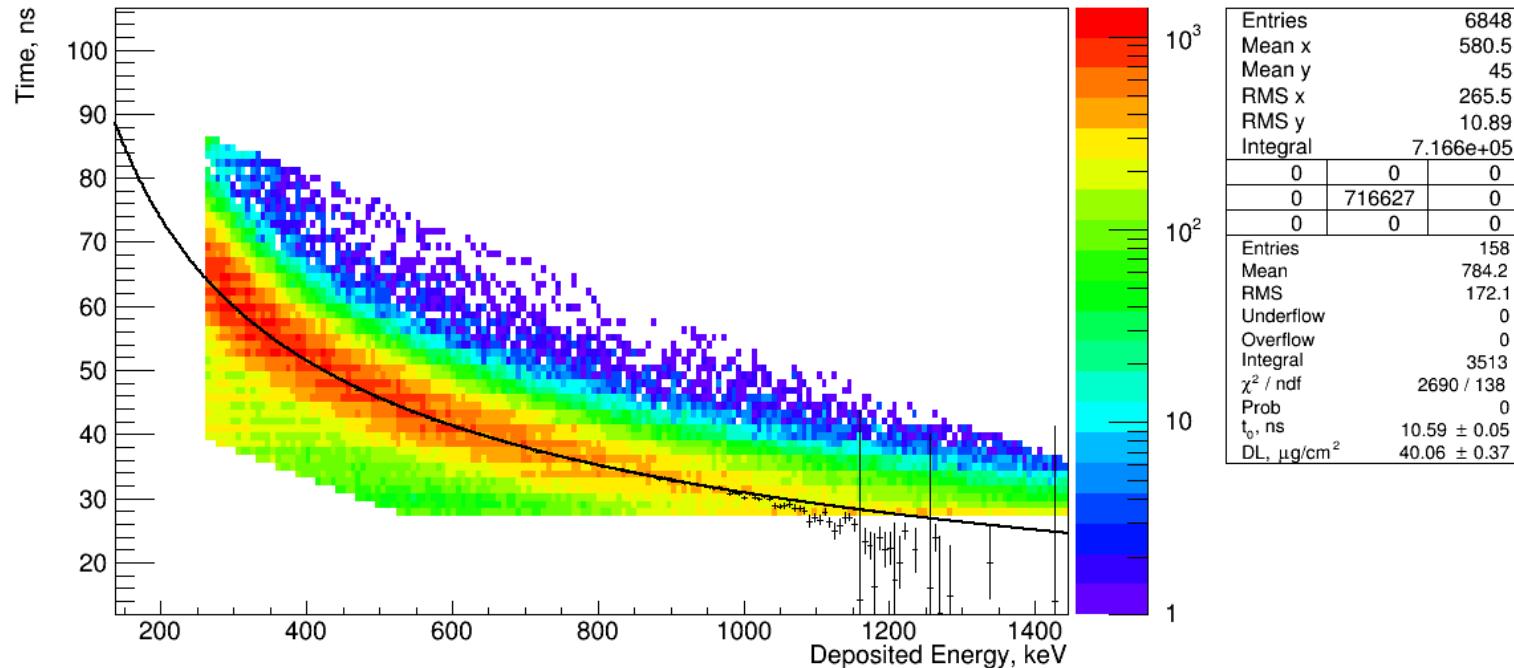
- Detectors energy-calibrated with  $\alpha$  sources  
 $^{241}\text{Am}$  (5.5 MeV) and  $^{148}\text{Gd}$  (3.3 MeV)
- Detectors are in the vacuum  $\approx 20$  cm from the beam
- No significant radiation damage observed



# p-Carbon Polarimeters: Signal Event Selection

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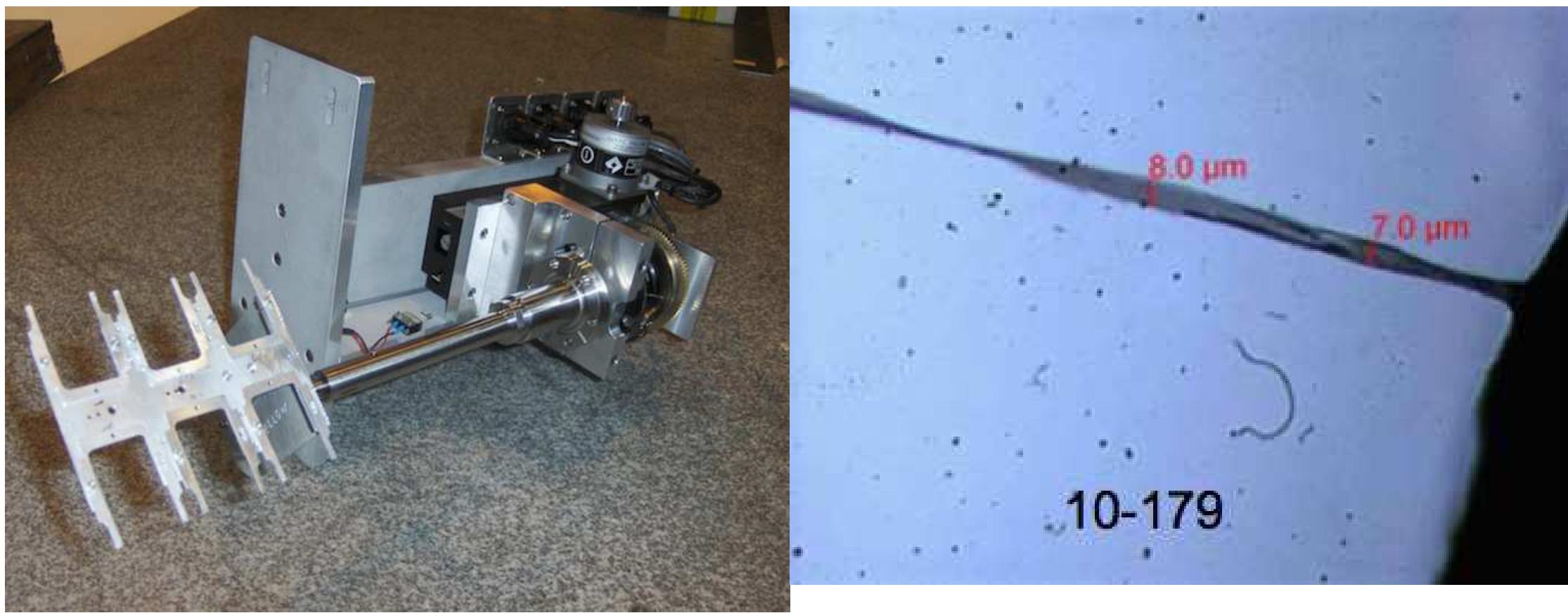
17558.004: Recorded Mon May 27 19:28:42 2013, Analyzed Mon May 27 19:53:58 2013, Version 2053, dsmirnov



- Calibration parameters **time offset**  $t_0$  and **effective energy losses**  $E_{\text{loss}}$  extracted from non-relativistic equation:

$$E_{\text{meas}} + E_{\text{loss}} = \frac{M_C}{2} \times \frac{L^2}{(t_{\text{meas}} + t_0)^2}$$

- Carbon events selected within a certain Time-Energy window optimized for minimum background

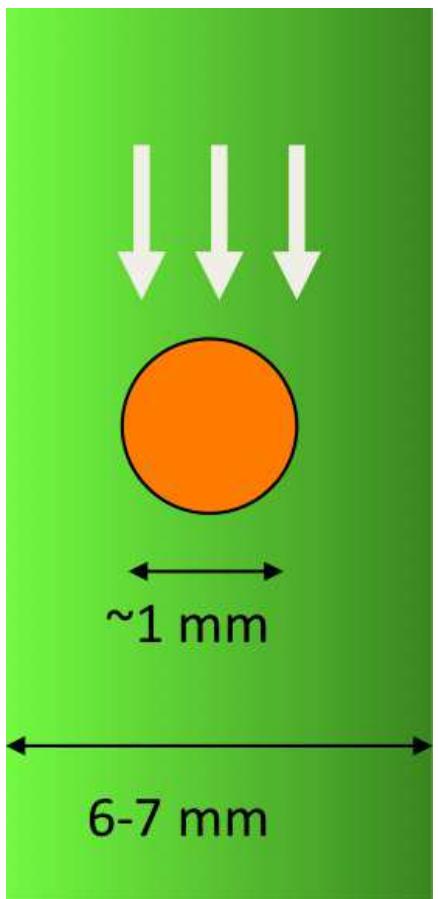


- Typical target size is  $2.5 \text{ cm} \times 10 \mu\text{m} \times 25 \text{ nm}$
- Targets are made by vacuum evaporation-condensation onto glass substrate
- Two stepping motors are used to move the ladder and to rotate the targets into the beam

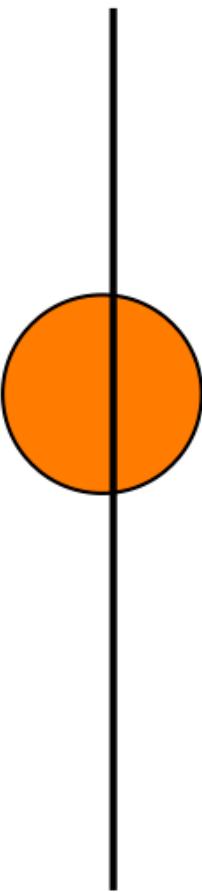
# Beam Polarization Profile

- If polarization varies across the beam the average polarization seen by polarimeters and experiments is different

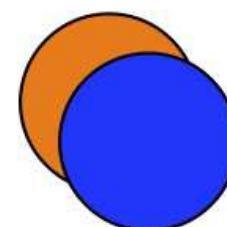
**H-Jet**



**p-Carbon**



**Beam collisions**



$$P = \frac{\int P(x, y)I(x, y)dxdy}{\int I(x, y)dxdy}$$

$$P_{\text{sweep}} = P$$

$$P_{\text{coll}} = \frac{\int P(x, y)I_1(x, y)I_2(x, y)dxdy}{\int I_1(x, y)I_2(x, y)dxdy}$$

- Polarization and intensity profile can be described with gaussian distributions:

$$P = P_{\max} e^{-\frac{\vec{x}^2}{\sigma_P^2}}, \quad I = I_{\max} e^{-\frac{\vec{x}^2}{\sigma_I^2}}$$

# Measuring Beam Polarization Profile

- Assume gaussian profiles:

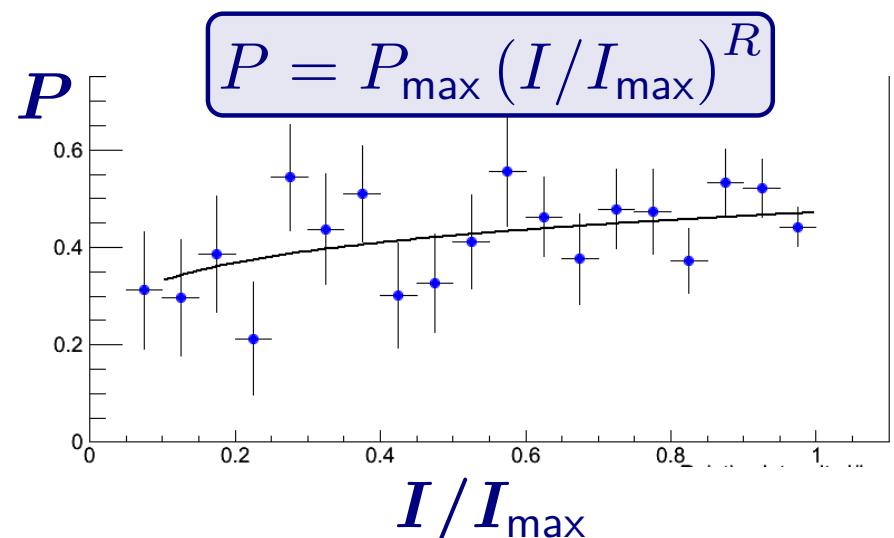
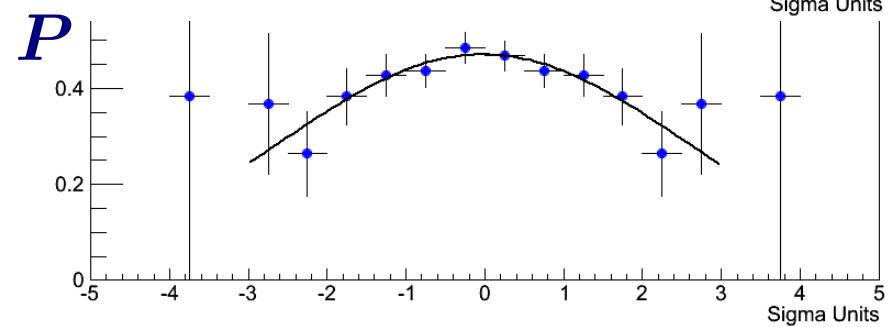
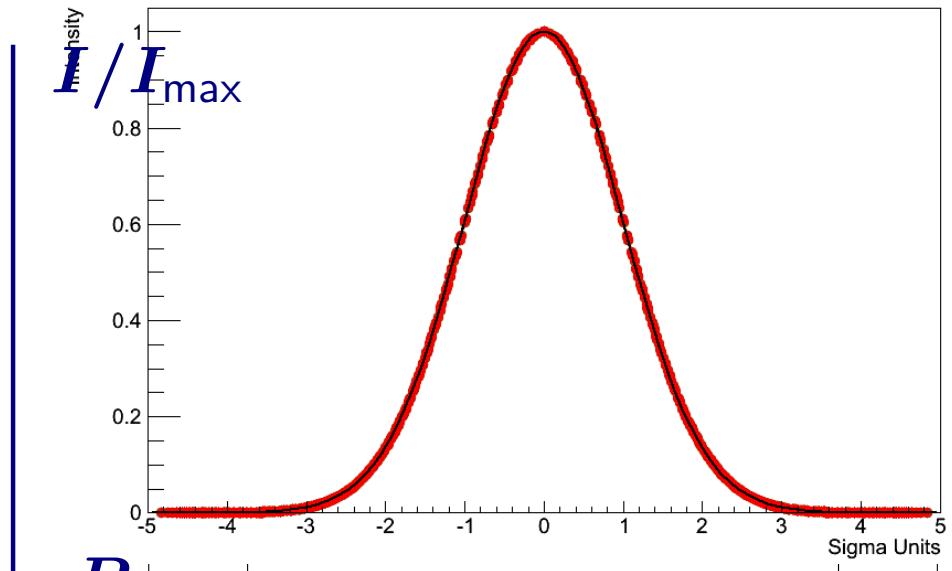
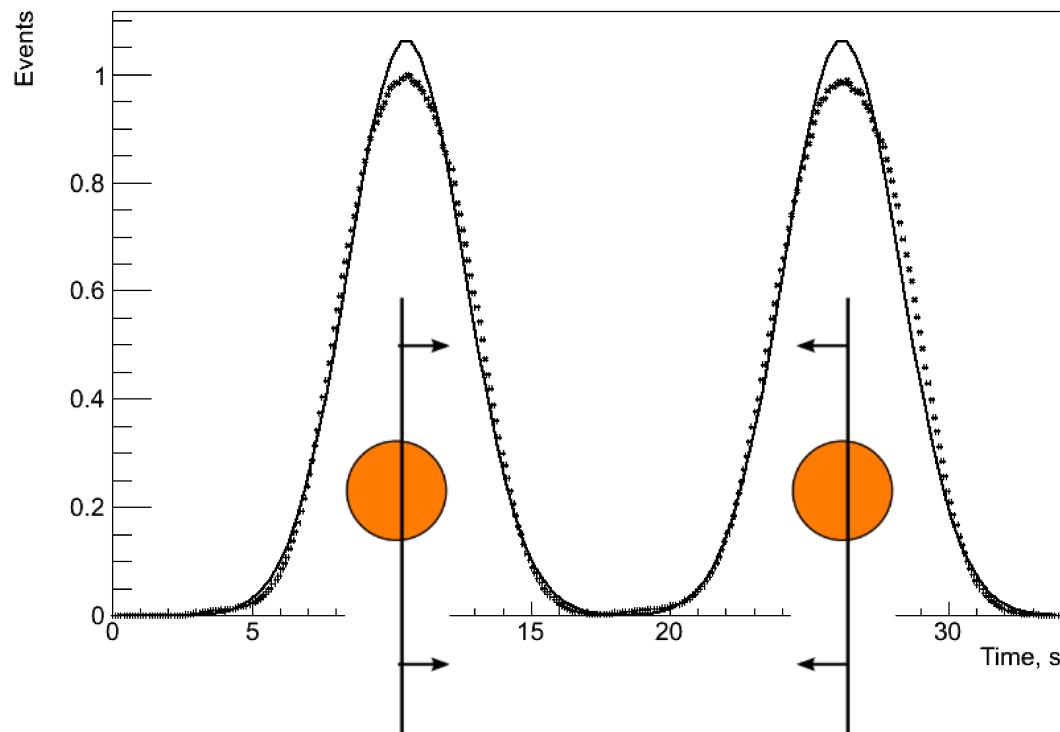
$$P = P_{\max} \exp\left(-\frac{\vec{x}^2}{\sigma_P^2}\right), I = I_{\max} \exp\left(-\frac{\vec{x}^2}{\sigma_I^2}\right)$$

- Polarization profile can be described by

- Center value  $P_{\max}$

- Profile parameter  $R = \frac{\sigma_I^2}{\sigma_P^2}$

- $R = 0$  if  $\sigma_P = \infty$  i.e. no Pol. profile



# Ultra-Thin Carbon Targets: Survival Rate

- 2009 (10 weeks) and 2011 (10 weeks) RHIC Runs
  - Carried through the runs on a single batch of targets
  - Some targets survived 300–400 measurements during 2–3 months
- In 2012 (10 weeks) and 2013 (14 weeks) RHIC Runs
  - Used three batches of 48 targets each

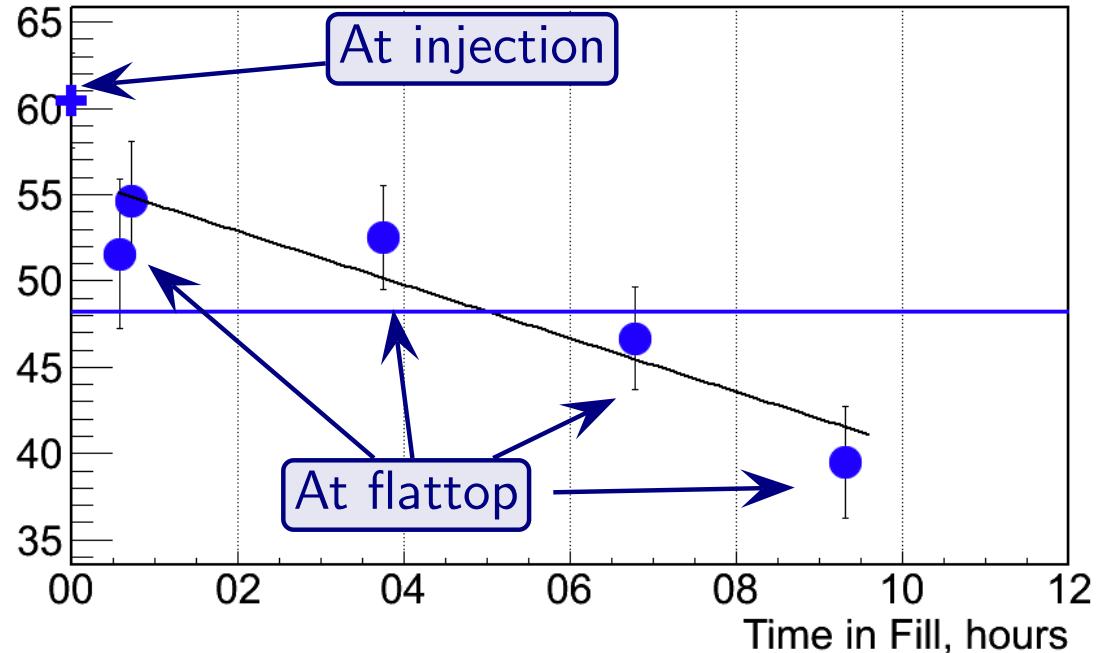
# Carbon Target Crossing Beam

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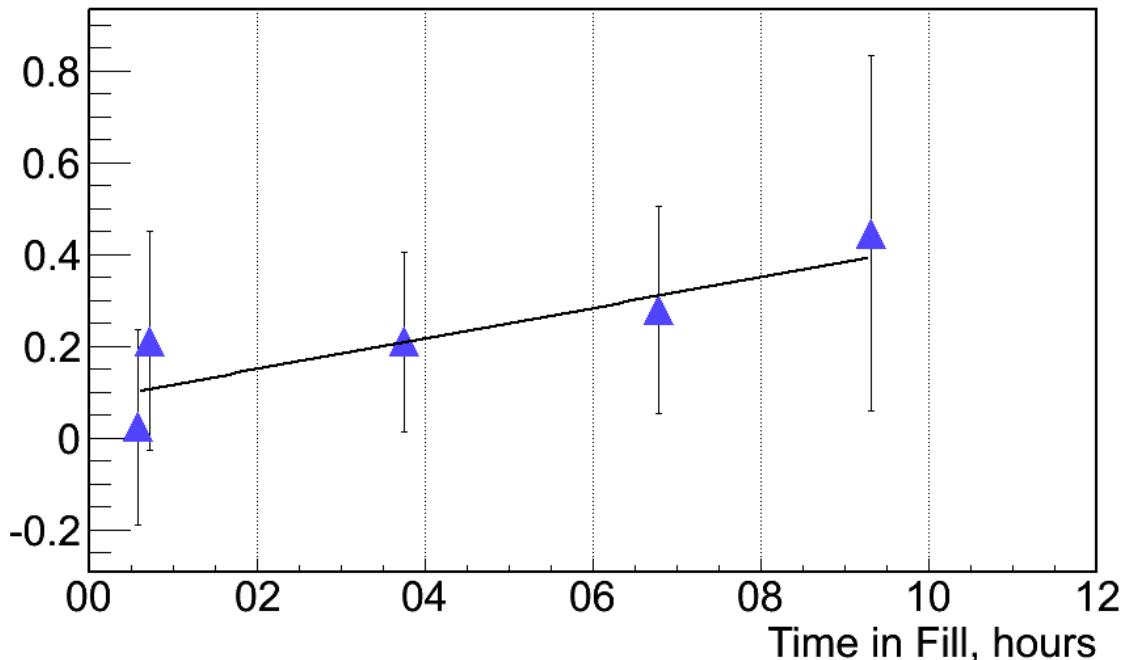
- The targets is attracted electrostatically to the beam
- No direct control of the amount of target material in the beam

- Observations (naturally statistically limited)
  - **Confirmed:** The targets graphitize after exposure with the beam
  - **An indication:** Thicker targets can survive longer
  - **A hint:** Targets may survive longer if first exposed to low intensity beams
- Solutions to mitigate target losses
  - Tried to graphitize the targets on the bench test (not very successful)
  - Move targets farther from the beam while not in use
  - Use thicker targets
  - Conserved targets by reducing the number of measurements
- Future tests:
  - New target ladder geometry with fins to reduce the electric field from induced charge

# Polarization Losses in a Fill

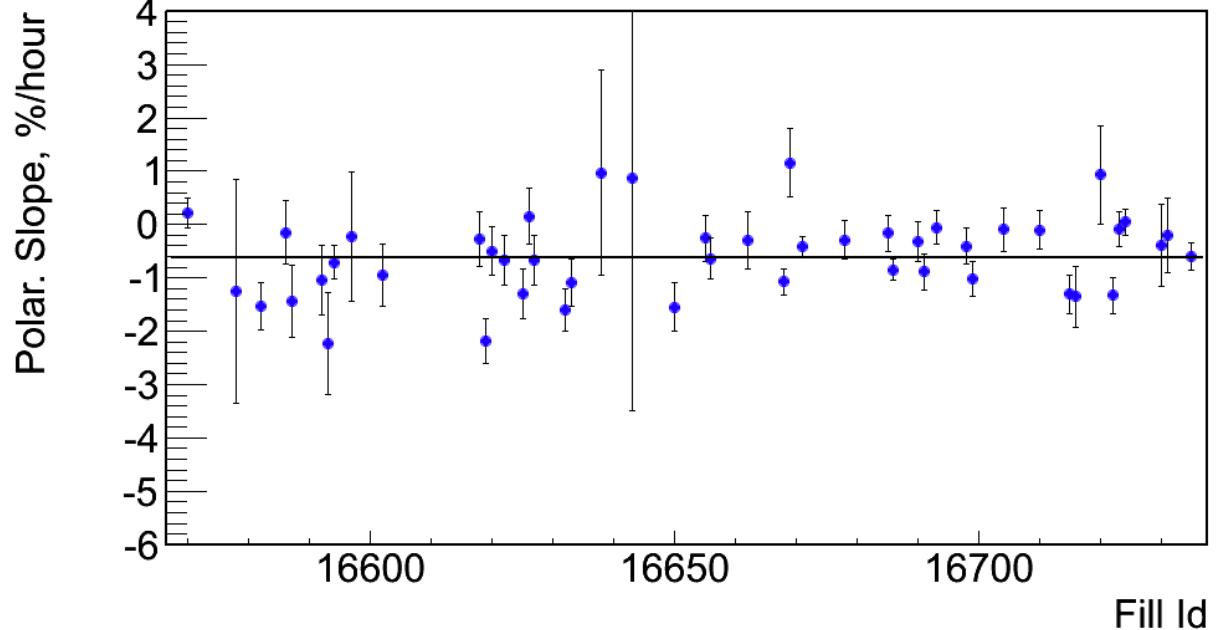


- Polarization is lost during beam acceleration
- Polarization decreases during the fill while  $R$  increases
- Losses consistent with beam profile broadening
- $R_v \sim R_h \approx 0.20$  for accelerated beam
- With  $\frac{dP}{dt}$  RHIC experiments can reweight individual fills according to their recorded luminosity



# Change in Proton Beam Polarization during a Fill

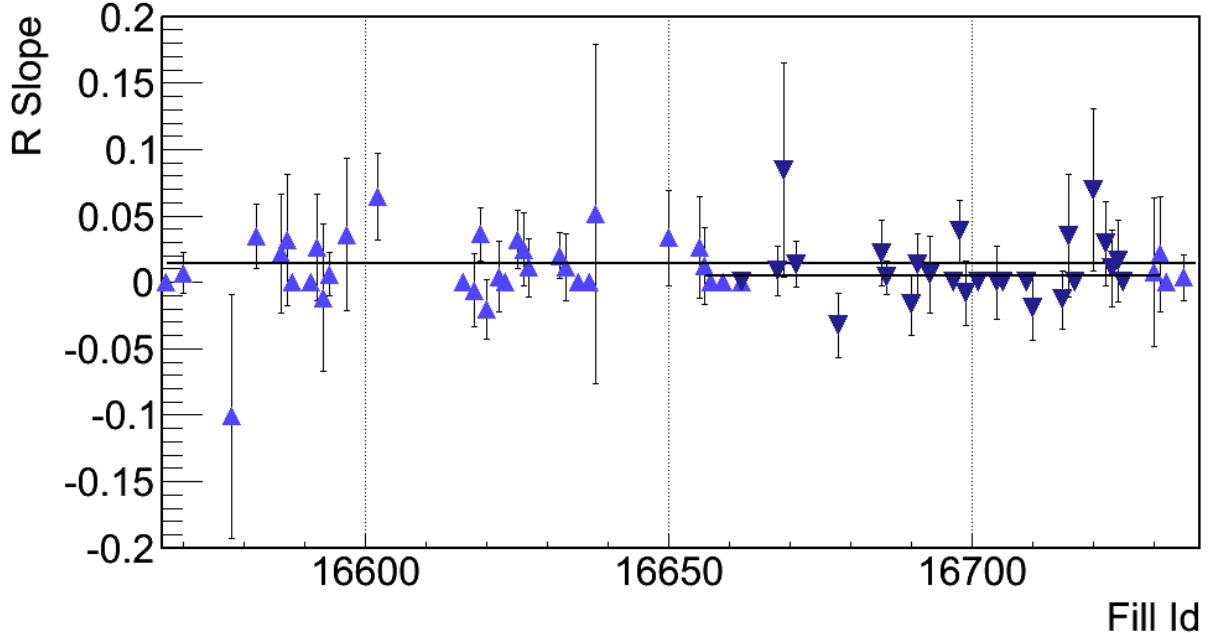
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- Linear approximation for beam polarization  $P$  and profile  $R$  in a fill:

$$P = P_0 + \frac{dP}{dt}t$$

$$R = R_0 + \frac{dR}{dt}t$$



- Average change in  $P$  and  $R$  is:

$$\frac{1}{P} \frac{dP}{dt} \sim -1\% \text{ per hour}$$

$$\frac{1}{R} \frac{dR}{dt} \sim +5\% \text{ per hour}$$

# Systematic Uncertainties on Polarization (In collisions)<sup>2 of 23</sup>

- Overall scale uncertainty  $\frac{\sigma(P)}{P} \approx 3\%$

- Due to normalization to the H-jet measurements
- Includes:
  - ~ 3% on H-jet target polarization,
  - ~ 1% due to background dilution, and
  - ≤ 2% reflects uncertainty in average difference between H-jet and pC

- Fill-to-fill uncorrelated uncertainty  $\frac{\sigma(P)}{P} \approx 5 - 8\%$

- Scales down as  $1/\sqrt{N}$  when fills combined
- Statistically dominated
- Includes:
  - ~ 2.2% due to possible profile miss-measurement. Determined as:

$$\langle P \rangle = \frac{P_{\max}}{\sqrt{1+R}} \quad \text{vs.} \quad \langle P \rangle_{\text{sweep}}$$

# Summary

- p-Carbon polarimeters at RHIC performed well in 2011, 2012, and 2013
- Minimal changes in the setup allowed for year-to-year systematic studies
- p-Carbon polarimeters work well for
  - Measurements of beam polarization profile
  - Statistically significant measurements of polarization losses during a RHIC store
- Ongoing efforts and improvements:
  - Target lifetime with higher beam intensities
  - More control over the amount of material in the beam
  - Absolute detector calibration will benefit in another “absolute” polarimeter
  - Potential to precisely measure pC  $A_N$  at very high beam energies